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METHOD FOR PRODUCING A LIGHT INTEGRATOR, A LIGHT INTEGRATOR, AND A USE THEREOF

The invention is directed to a method for producing a light integrator and to a light integrator for homogenizing a light bundle entering an input surface and exiting from an output surface. The invention is further directed to a use of this method.

Light integrators are known. In principle, they comprise a body which is coated uniformly by reflecting material in which the light is introduced, the light is then repeatedly reflected back and forth at the reflecting surfaces. Because of the multiple reflection, the origin of the light for the light bundles exiting at the output is lost to a great extent. In this way, a homogenized illumination surface is achieved.

Integrators are used wherever especially uniform illumination is desired, for example, in imaging technology where every image component to be imaged should receive the same amount of light.

EP 0 734 183 A2 proposes a light tunnel which is inserted between illumination optics and an LCD matrix to be illuminated. This light tunnel, as it is called, is an elongated rectangular parallelepiped, for example, whose opposing surfaces on either side of a longitudinal axis determining the principal propagation direction of the light are utilized as light inlet and light outlet surfaces. The other surfaces at right angles to the principal propagation direction of the light are used as mirror surfaces.

Further, it is indicated in this reference that total reflection can also be utilized in that this rectangular parallelepiped is produced in a simple manner from one piece of smooth polished glass and the angles for coupling in are selected such that the reflection is carried out at the sides by total reflection.

Total reflection is extremely advantageous for these purposes because few losses need be taken into account. The only losses occurring in such light integrators in theory are caused by the absorption of the material; but this absorption can be suppressed to a very great extent when a glass of corresponding purity is used for producing an integrator of this kind.

However, holding a light tunnel or mixing rod of this kind presents difficulties. Every contact with the outside surface reduces and interferes with total reflection, so that there is a risk of corresponding losses due to scattering.

The principle of image generation such as it is presented in the European Patent, for example, is based on the light beams which are parallelized again after the light tunnel being directed to at least one LCD matrix. For image generation, the LCD matrix is controlled, for example, with a control device for showing video images. In principle, a video image could be projected into a screen as a large image with the technique known from slide projection or, as with the episcope, could project the reflected light with LCD matrices with reverse reflective coating.

This large-image technique is looked upon as promising in terms of future developments because electronic picture tube technology cannot be used with very large images.

When using the reflected light projection method, a mirror matrix can be provided for image generation instead of the LCD matrix. A matrix of this kind is available, e.g., as a circuit, from Texas Instruments. In this circuit, a plurality of tilting mirrors, one for each image point, which are arranged in the form of a matrix is digitally controlled. In one of the digital states, every tilting mirror reflects the full light intensity; in the other state, the mirror receives and reflects the light at an angle at which it can no longer be projected onto the screen, i.e., the corresponding image point on the screen is dark with the exception of small proportions of scattered light.

The different brightness for showing a gray value or color value of a picture point can be brought about in that the mirrors are acted upon by pulse trains, so that only an intermediate value between the full light intensity and dark is detected in the eye of the observer for every image point averaged over time.

However, the large-projection method mentioned above imposes very strict requirements on the light integrator. That is, large light losses cannot be permitted in large-image projection if there is to be a sufficient quantity of light for an image projected onto a screen. As has already been made clear, only total reflection is suitable for this purpose, in principle; however, the support of a mixing rod presents difficulties because it can lead to excessive light losses. Further, the light inlet surface and outlet surface are exposed to a high energy flow of light and can accordingly change color. Further, dust on the inlet surface and/or outlet surface inevitably reduces the light flow in an uncontrolled manner. Because of these disadvantages, it would be extremely desirable to use other light integrators.

In order to prevent interference of reflection, as in total reflection, it is conceivable that all outer surfaces could be provided with a reflective coating in the rectangular parallelepiped-shaped rod mentioned above. However, this would result in the further disadvantage of cumulative light losses from the material and mirror.

In order to eliminate losses caused by material at least, it would be possible to guide the light inside a cavity with internal reflective coating. However, this idea can hardly be realized in optimal manner in practice because, as every person skilled in the art knows, a uniform internal reflective coating with sufficient mirror quality for minimizing losses cannot be realized in practice.

~~It is the object of the invention to provide an integrator which is optimized with respect to the amount of light that is transmitted, but which does not have the disadvantages of a totally reflecting rod.~~

This object is met by a method for producing a light integrator which has the following steps for forming a cavity of the integrator having an inner reflective coating:

- fabrication of at least two parts from which the light integrator can be assembled and whose surfaces, provided as inner sides of the cavity, are exposed;
- rimless reflective coating of at least the surfaces of the parts which are provided as inner sides of the cavity;
- assembly and fastening of the parts.

This results in a light integrator according to the invention for homogenization of a light bundle entering an input surface and exiting from an output surface, characterized in that it has a cavity with an inner reflective coating for conducting light, wherein the light integrator is composed of at least two parts whose surfaces which are exposed prior to assembly and face inward after assembly are provided with a reflective or mirror layer.

Accordingly, of the alternatives discussed above, the cavity with internal reflective coating is preferable. As was already explained above, this alternative would not have been reasonable at all and would not even have been considered by the person skilled in the art because an inner reflective coating with a permissibly low degree of losses would not have been possible at all. Prior to the invention, the only recourse would have been to provide a silver coating in the interior by vacuum deposition, for example; but this oxidizes easily when it is not provided with a protective layer. This protective layer would also cause absorption again.

In particular, it can easily be calculated that with a reflection factor of 96% and 5 reflections, 20% of the light in the integrator would be lost; and it is questionable whether such a high reflection factor could even be achieved. It is only by taking apart the cavity, according to the invention, that is, dividing the integrator into at least two parts, wherein the inner sides of the cavity are exposed with respect to the reflective coating, that it is possible to produce highly reflecting layers with a reflection factor of 98%, for example, by applying dielectric layers to the metal coating. With a reflection factor of 98%, which is certainly attainable in this way, a transmission of greater than 90% is provided with 5 reflections; that is, a loss of only 10% need be taken into account.

Further, it is possible to apply an essentially dielectric mirror possibly with a thin metal layer beneath it as back coat so as to further reduce losses.

The light propagates essentially in air in a cavity integrator, so that the losses are determined solely by the mirror layers and optionally low, permissible losses in the integrator can be achieved in accordance with expenditure. However, the assembly of the parts could cause additional losses, for example, due to glue at the glue joints. In particular, care should be taken that no glue accidentally falls on the mirror layers because this would result in proportionately high waste. Fastening the parts to one another with glue or by screw connection would also be time-consuming, which would add unnecessarily to the cost of producing an integrator of this kind if another possibility were not found.

According to a further development of the invention which is preferred in this respect, it is provided that the step for fastening is carried out by means of the following sub-steps:

- covering the assembled parts with shrink tubing;
- shrinking the tubing until a suitable strength of the cavity integrator is achieved.

In this way, a light integrator according to the further development is characterized in that the parts are held together by means of at least one piece of shrink tubing.

The method of providing parts with shrink tubing is known from electrical engineering, wherein a piece of tubing which is larger than the location to be insulated, for example, a solder joint, is placed over the latter for fast insulation. By applying heat, for example, hot air, the tubing shrinks and completely encloses the solder joint, for example.

This method was previously provided exclusively for insulation and has proven to be a fast procedure for this purpose. It is used herein for the first time for fastening purposes.

This type of fastening is characterized by simple and fast handling. But also, due to the elasticity of the shrink tubing, the pressure is automatically distributed on the joined parts, which are preferably made from glass, and breakage or other damage to parts is prevented.

Further, due to its elastic tensioning, the shrink tubing ensures that the parts to be fastened are pressed very close together. With polishing grades commonly used in optics, this means that the parts can contact one another so as to be practically light-proof. Accordingly, there is only a slight chance that the light within the cavity could reach the area between contacting surfaces of the parts from which the light integrator is composed where it would no longer be available for illumination. This result could only be achieved in small measure with a glue and would also not be reproducible because the spacing of the parts would then be determined essentially by the amount of glue.

When production is carried out using glass and glue, positional tolerances of the opening of only +0.2 mm can be achieved, whereas positional tolerances of less than 0.05 mm can be realized when fastening with plastic.

With respect to the fastening of the shrink tubing, two main alternatives are preferred:

1. Fastening by holding the parts together by means of shrink tubing arranged in the middle between the input surface and output surface;

2. Fastening by holding together the parts in the vicinity of their input surface and output surface by two pieces of shrink tubing enclosing the integrator.

The following further developments have to do essentially with the shaping of the parts in order to provide the most favorable possible integrator with respect to manufacture, economy and reproducibility. Preferred further developments of this kind are characterized in that:

- one part is provided with a projection engaging in a cutout of the other part after assembly;
- the inner sides and outer sides of the light integrator which form the cavity are planar, the light integrator has the shape of a geometric prism with rectangular

bottom and top surfaces provided as outlet and inlet surfaces, and the projection and cutout are rectangular, particularly square;

- the light integrator is composed of two T-shaped and two I-shaped side parts.

Above all, the projection in the cutout not only provides for a reproducible assembly, but also reduces a possible gap in which light could be lost, wherein the residual gap can be kept very small by means of pressing, for example, by means of the shrink tubing mentioned above.

The above-mentioned shaping with rectangular projection and cutout simplifies manufacture above all. In particular, the assembly of two T-shaped side parts and two I-shaped side parts simplifies the arrangement of the mirror layers. Further, there are only two sorts of parts, namely, T-shaped and I-shaped, which can then be produced in a simple manner by mass production. The embodiment examples shown in the following once again illustrate the most advantageous shaping of the individual parts.

Because of the low light loss, the use of such integrators for homogenization of the light coming from a light source provided for the illumination of an electronically controllable matrix for showing image elements is extremely advantageous. While the illumination of LCD matrices is already known from the prior art, it is also provided according to the invention that the matrix is a tilting mirror matrix when used in this way.

Further particulars of the invention are indicated in the following description of embodiment examples with reference to the accompanying drawings.

Fig. 1 is a schematic view illustrating the manner of operation of a light integrator using the example of projection with a matrix, particularly a tilting mirror matrix;

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Fig. 2 shows a perspective view of an integrator according to the invention;

Fig. 3 shows a front view of the integrator of Fig. 2;

Fig. 4 shows another embodiment example for an integrator according to the invention.

The use of an integrator 2 for illuminating an LCD matrix or DMD matrix, referred to hereinafter as tilting mirror matrix, is illustrated schematically in Fig. 1. Its application is not restricted to matrices of this type for electronic image display; however, it is extremely advantageous to use an integrator of this type for illumination of such matrices, particularly because a tilting mirror matrix 4 has very small dimensions of less than 1mm*1mm, a surface which cannot be illuminated uniformly when focusing with high luminous densities alone because the light spot usually has the same dimensions when focusing the light of a lamp with high luminous density.

The entire arrangement shown in Fig. 1 is arranged on one optical axis 6. This is also not limiting. An arrangement, e.g., optics, whose optical axes are offset relative to one another can also be put together.

A light beam 8, shown by way of example, which can be generated by means of a lamp provided with a parabolic mirror, is introduced into the input surface 12 of the integrator 2 through in-coupling optics 10. The light beam 8 is reflected back and forth repeatedly inside the integrator 2 which has a reflective coating on the inner side of the side parts 14 or when the integrator 2 comprises a medium with a suitable index of refraction for total reflection. This results in a pseudostochastic distribution of the entering light beams 8 in the light outlet surface 16.

Because of the pseudostochastic distribution, the light beam 8 is highly homogenized at the output of the integrator. It can be parallelized again by out-coupling optics 18 as is shown schematically in Fig. 1. The light bundle which is homogenized in this way is then directed onto the tilting mirror matrix 4 from which it is subsequently directed into projection optics which project the image that is generated electronically by the tilting mirrors of the titling mirror matrix 4 onto a screen, thereby making it visible to the observer.

Fig. 2 shows an integrator 2, according to the invention, which is advantageous particularly for application with a tilting mirror matrix 4. The integrator 2 is a cavity integrator which has a reflective coating on the inner sides of the side parts 14, 14'. A cavity integrator is characterized above all by the fact that the inlet surface 12 and the outlet surface 16 are not thermally loaded, so that no changes in color occur with high light output and no dust particles can collect. An integrator 2 which is constructed as a cavity integrator is particularly advantageous when using small tilting mirror matrices because especially high luminous densities are used in this case.

In order to provide the cavity integrator with internal reflective coating in a simple manner, the cavity integrator is composed of four parts, two T-shaped parts 14' and two I-shaped parts 14. The arrangement and shape of the parts can also be seen particularly from Fig. 3. The T-shaped parts and I-shaped parts are shaped and pressed together in such a way that they do not allow any shearing movement relative to one another. The parts could also be shaped differently and put together with a cutout in the manner of tongue-in-groove so that an exact right-angled geometry is always ensured. However, due to the I-shaped parts 14 and the T-shaped parts 14' in which a corner 20 of the I-shaped part fits exactly into a cutout 22 of the T-shaped part, a particularly good hold is always ensured, but tilting cannot lead to breakage of the material.

The entire integrator 2 is held together by means of shrink tubing 24.

A production method for an integrator shown in Fig. 2 and Fig. 3 is accordingly relatively simple. The individual parts 14 and 14' are manufactured, for example, by injection molding from plastic, from glass or the like and are given a rimless reflective coating on the inner sides. Because of its high reflection factor, silver is particularly suitable as reflective coating. With reflection factors which should be substantially higher than 96%, however, a dielectric mirror layer should advisably be provided which can serve at the same time as a protective layer.

The reflective coating is carried out in a substantially rimless manner, so that all surfaces of the parts 14 and 14' open to the inner side have a reflective coating with a high reflection factor when fitted one inside the other according to Fig. 3. After assembly, shrink tubing 24 is fitted over the parts. By treating with heat, this tubing shrinks and holds the parts 14 and 14' together with the greatest possible stability, also due to the corner 20 which fits into the cutout 22. The elasticity of the shrink tubing enables simple assembly, particularly also with respect to the reduced risk of breakage when fastening when the parts 14, 14' are produced, as they usually are, from breakable material, particularly glass.

Fig. 4 shows an integrator similar to that shown in Fig. 2, but with two slight modifications. First, instead of only one piece of shrink tubing 24, two pieces of shrink tubing 24' and 24" are provided, which ensures better holding particularly at the ends. Second, a cutout 26 is made in the area of the input surface 12 in order to increase the compactness of a device constructed in practice according to Fig. 1. In the embodiment example, a screw head which would otherwise be bothersome is accommodated in the cutout

26. The light losses of a cutout of this kind are correspondingly small when the angle attained by the in-coupling optics 10 is large enough for this cutout 26 to lie outside of the first reflection.

Further, it can be seen from Fig. 4 that shapes other than two T-shaped and two I-shaped parts 14, 14' are possible.

In this respect, it must be stated that the invention can even also be realized when only two right-angled parts with corresponding cutouts are joined together. However, particular when manufacturing from glass, the arrangement of four parts is substantially more favorable because there are always plane surfaces which can be correspondingly precisely ground and polished.

The preceding embodiment examples illustrated, above all, the simplicity of the construction and, therefore, a more economical method for producing an integrator 2 of this kind. Further, the person skilled in the art will immediately discern some modification possibilities which lie within the scope of the invention. For example, two or three pieces of shrink tubing can also be used instead of a single piece of shrink tube 24. Moreover, the shaping of the parts 14 and 14' can be correspondingly modified, for example, by providing a tongue-in-groove connection between the parts.

Changes of this type are possible. However, the embodiment examples of Fig. 2 to Fig. 4 are particularly preferred, also because, among other reasons, a tongue-in-groove connection, for example, would increase the danger of breakage at the edges of the groove or the corners of the tongues when incorrectly inserted, for instance. The illustrated examples are also especially optimized for a simple and quick assembly of the parts 14 and 14' when manufacturing the integrator 2.